

Hydrogeochemical evaluation of groundwater of Bhaktapur Municipality, Nepal

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Received: 4 January 2015 / Accepted: 5 May 2015 / Published online: 26 May 2015
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Abstract The present study aims to evaluate groundwater hydrogeochemistry of Bhaktapur Municipality, Nepal with respect to water types, chemical elements and their statistical variability. Samples were collected in pre-monsoon (April–June), monsoon (July–August) and post-monsoon (October–November) seasons in 2007. Laboratory analysis of samples revealed inter-seasonal variability, primarily attributed to hydrogeochemical processes. All or most of the samples exceeded the World Health Organization (WHO) guideline value (GLV) for iron, conductivity and turbidity, while none of the samples exceeded WHO GLV for hardness and arsenic with minor fraction exceeding GLV for chloride content. Higher ammonia content in well water and highest phosphate concentration occurred for stone spout in pre-monsoon season. Principle component analysis highlighted three principle components while the dendrogram divided the sampling sites into four and two clusters, respectively, for well water and stone spout water sampling sites. Saturation index computed through WATEQ4F model revealed that ferrihydrite, siderite, strengite and vivianite minerals were in under-saturated state, while goethite was in supersaturated condition for each type of samples (well water and stone spout water) in both pre- and post-monsoon seasons depicting their

tendency to precipitate. High degree of supersaturation in goethite mineral indicated response to temperature gradient of the reactions, while under-saturation for other minerals indicated the effect of dilution.

Keywords Groundwater · Hydrogeochemistry · Saturation index · WATEQ4F model · Bhaktapur

Introduction

Life on the earth depends on water which is a vital commodity for all living creatures. Most of the lentic water bodies are polluted and unsafe for drinking (Diwakar and Thakur 2012; Diwakar et al. 2008). Increasing water demand has forced people to depend on groundwater (Singh et al. 2013a) resulting in high water extraction from groundwater reserves (Singh et al. 2006; Thakur et al. 2013). Residents of Bhaktapur Municipality heavily depend on groundwater sources for drinking and other household purposes (Diwakar and Thakur 2012). However, groundwater quality in the study area is deteriorated by anthropogenic activities such as urban storm water infiltration, industrial and sewage effluents, leaching of synthetic fertilizers, pesticides and insecticides containing heavy metals (Thakur et al. 2011). The fate and impact of the chemical discharge is largely the function of hydrogeochemistry of the soil–groundwater (Miller 1985; Paudel et al. 2014). It is thus important to assess the hydrochemical properties and record information about geological settings of the sample and the descriptive information (Howarth 2013). Statistical analysis of wide range of dataset helps to determine the spatial variation in groundwater quality relationship among various parameters (Thakur et al. 2012; Singh et al. 2013c). Similarly,

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saturation index is the key to evaluation of various stages of hydrochemical evolution of the particular groundwater system. Hydrogeochemical evaluation of groundwater composition helps to understand groundwater quality for drinking, agricultural and industrial purposes (Kumar et al. 2006; Prasanna et al. 2010).

Prommer et al. (2000) adopted numerical model to stimulate contaminants (benzene, toluene, ethylbenzene, and xylene) migration into groundwater to evaluate remediation measures. Singh et al. (2006) assessed surface and groundwater samples of in Indo-Gangetic alluvium region using the base-exchange, meteoric genesis, Langelier saturation and Ryznar stability indices, soil–water interactions and impact on groundwater quality using ion flux coefficient (cf). Kumar et al. (2007) evaluated temporal variation in groundwater quality for the suitability of irrigation and potability. Navarro and Carbonell (2007) analyzed hydrogeochemical changes of the La Llagosta aquifer of the central Besos river basin, Spain using iso-concentration maps, hydrogeochemical diagrams. Srivastava and Ramanathan (2008) performed geochemical evaluation of groundwater quality in the vicinity of Bhalswa landfill, Delhi, India, using a hydrochemical approach with graphical and multivariate statistical methods.

Shrestha and Kazama (2007) used multivariate statistical techniques such as cluster analysis (CA), principal component analysis (PCA), factor analysis (FA) and discriminant analysis (DA) to evaluate spatial/temporal variations and interpretation of large complex water quality data set. Alkarkhi et al. (2008) analyzed heavy metals concentrations in river estuary through multivariate analysis. Facchinelli et al. (2001) used multivariate statistical approach to identify heavy metal sources in soils. Dwivedi et al. (2015) analyzed geochemical trends of heavy metal in aquifer system of Kanpur Industrial Zone to ascertain the contamination profile in groundwater. Dwivedi and Vankar (2014) used multivariate statistical analytical approach for source identification of heavy metal contamination in the industrial hub of Unnao, India.

Most of the hydrogeochemical studies of groundwater are focused in the Terai region of Nepal (Bhattacharya et al. 2003; Diwakar et al. 2014; Gurung et al. 2005; Khadka et al. 2004; Shrestha and Shrestha 2004; Williams et al. 2004). Less attention has been given to the hydrogeochemical studies of groundwater in the Bhaktapur district. There is a gap in understanding hydrogeochemical characteristics of groundwater quality in Bhaktapur Municipality area where most people depend on groundwater for drinking. The main objective of this research is to evaluate the hydrogeochemical characteristics of groundwater of Bhaktapur Municipality with the integrated application of statistical as well as hydrogeochemical techniques.

Study area

The Bhaktapur Municipality with an area of 6.88 Km² is located in the Bhaktapur district, Bagmati, Central Development Region, Nepal (Fig. 1). It lies 13 km east of Kathmandu, between 27°36' to 27°44'N Latitude and 85°21' to 85°31'E Longitude, with an elevation of 1401 m above sea level. The geographical boundary of the study area is delimited by Bageshowri, Sudal, Tathali and Chitapol Village Development Committee (VDCs) in the east, Madhyapur Municipality in the west, Chhaling, Jhaukhel, Duwakot VDCs in the north and Sipadol and Katunje VDCs in the south. It contains seventeen wards (HMG/MYSC 1990). The climate is sub-tropical, temperate and cool temperate with maximum monthly temperature in the month of June or July and minimum in January (Kansakar et al. 2004). The average temperature of coldest month reaches as low as −2 °C during the winter and over 32 °C in summer. The rainy season (June–September) accounts 80 % of the annual rainfall (1362.2 mm). Population growth rate in Bhaktapur is estimated to be 2.96 % with the population of 303,027 (CBS 2011). Bhaktapur presents mixed ethnic groups. In terms of water resources, it consists of 87 stone spouts, 220 wells and 7207 piped lines (185 public taps) (Diwakar et al. 2008).

The total population of the Bhaktapur district is 304,651 (NPHC 2011a). Of the total 68,557 sources of drinking water, 53,438 households have access to tap/piped drinking sources; 2607 households have access to Tubewell/hand-pump; 4775 draw water from well; 3342 depend on stone spouts and 42 households depend on river or stream as the source of drinking water (NPHC 2011b).

Geology of the region

The Bhaktapur Municipality is located in the weak geological structure having number of fault lines, with low bearing capacity and loose soil structure as physical limitations (Chapagain et al. 2010; Shrestha et al. 1999). The basement of the district is formed by Precambrian to Devonian rock which are intensely folded, faulted and fractured igneous and meta-sedimentary rocks and overlain by Quaternary fluvio-lacustrine deposit with the thickness of 550–600 m (Chapagain et al. 2010). The Kalimati Clay is rich in organic matter, plant fossils, diatoms, and natural gases (Fujii and Sakai 2001; JICA 1990). The Kalimati formation with the clay layer of minimum thickness of (<10 m) having low bearing capacity covers the area (JICA 1990). Fault lines are spread around the municipality which possesses limitation for construction, making most of the settlement area vulnerable. The soil found in and around the municipality is suitable for crop cultivation

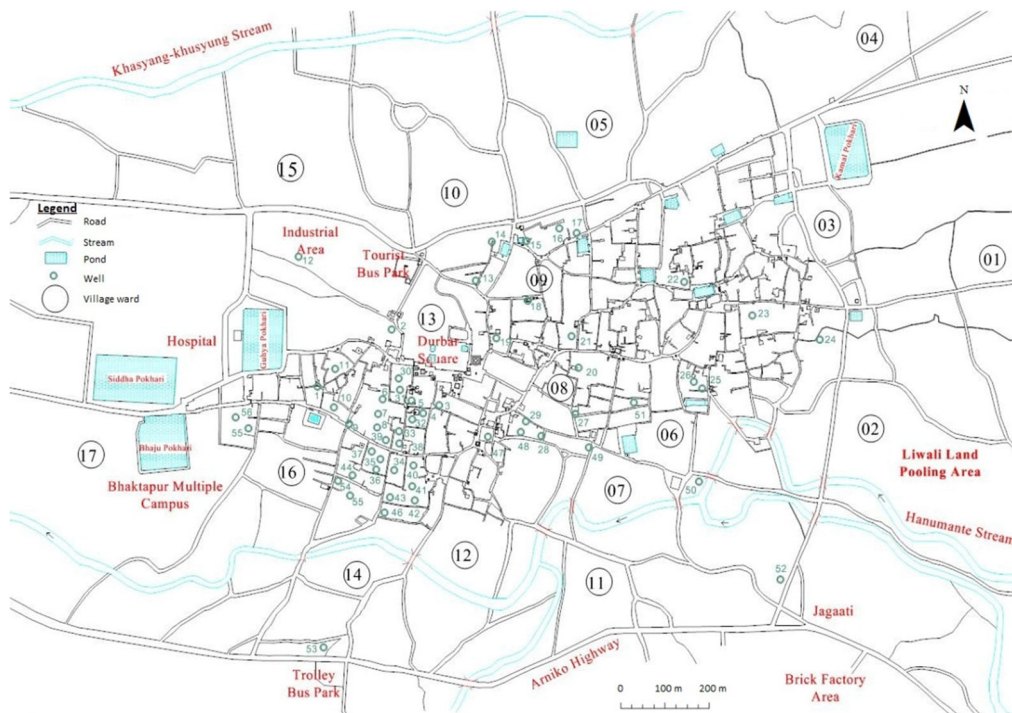
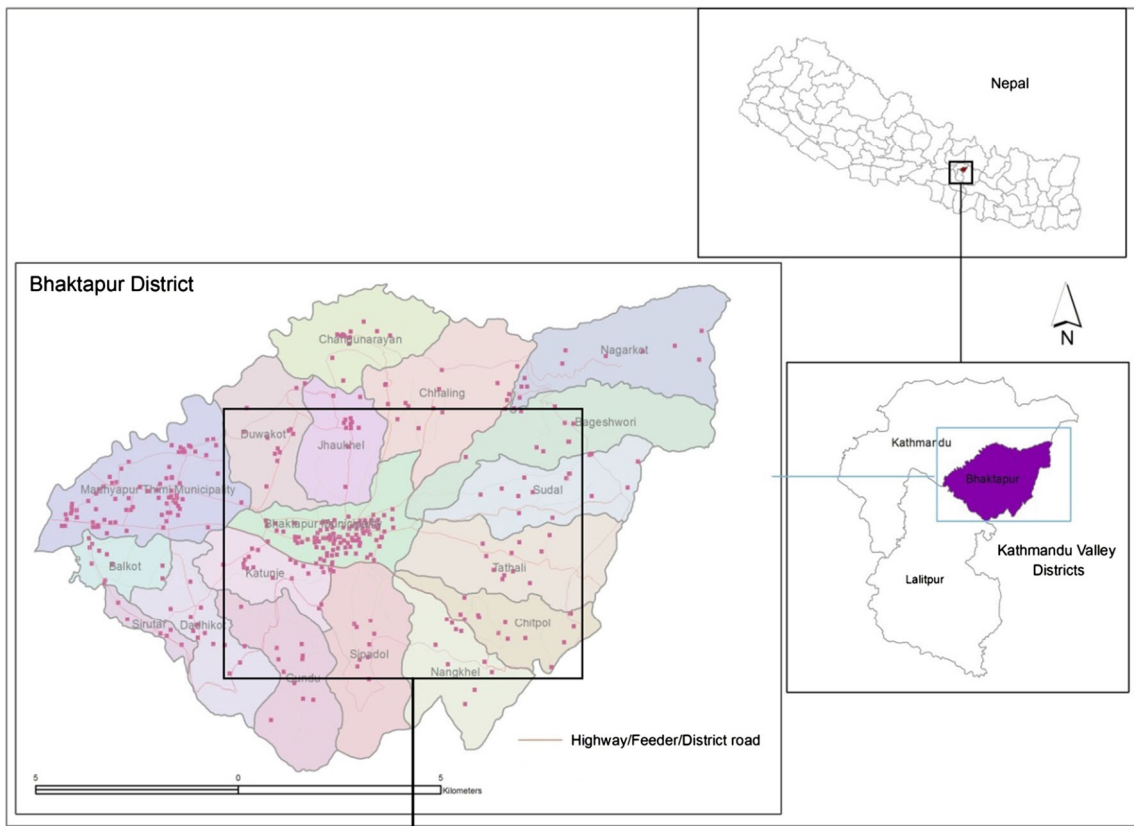


Fig. 1 Location map of Bhaktapur Municipality showing sampling locations

(Shrestha et al. 1999). In the study area, sticky clay constitutes top soil along with fine and coarse sand followed by clay with pebbles, cobbles and boulders over consolidated hard rocks of quartzite, basalt, granite, etc. (BDC 2011).

The grain size of the core sample ranges from sticky clay (0–5 m), cobbles and boulders (100 m) to the consolidated hard rocks of quartzite, basalt and granite up to depth of 300 m. The bulk concentrations of the oxides and trace elements vary considerably (Fig. 2).

Methods

The methodology for the research consists of three different stages, viz., pre-field work, field work and post-field work. The detailed methodology is shown in Fig. 3.

In the first stage, a literature review on hydrogeochemical evaluation of groundwater in various parts of the world has been carried out. In the second stage, field work was carried in the study area to collect water samples. Laboratory analysis, hydrogeochemical and statistical analysis of obtained data were carried out as post-field work.

Field methods and sample collection

In this study, 85 water samples were collected randomly during each of the three seasons from three different types of sources namely stone spouts, well and tube wells from

the study area. First, the area was divided into rectangular grid blocks which were given numbers. A random number generator function was used in an EXCEL sheet to create random number table, which was used to select the grid points at which samples should be selected. The Sampling was done in pre-monsoon (April–June), monsoon (July–August) and post-monsoon (October–November) seasons in 2007. The sampling locations were sensibly fixed by GPS (Garmin Model 780). On-site measurements of temperature, pH and electrical conductivity (EC) were made using an in-line flow cell to ensure the exclusion of atmospheric contamination and to minimize the fluctuations. The portable Orion Thermo water analyzing kit (Model Beverly, MA, 01915) was used for all on-site measurements.

Laboratory-based hydrochemical analysis

The samples collected from each location were filtered using 0.45- μm Millipore membrane filters. The collected samples were preserved with concentrated HCl. Samples were brought to the Nepal Academy of Science and Technology (NAST) laboratory and stored below 4 °C temperature. The preservation under refrigeration was done for 24–48 before analysis. The samples were analyzed for anion and cations concentrations.

Total alkalinity (titration method), total hardness (EDTA method), chloride (argentometric titration method),

Fig. 2 Lithology of a borehole through an aquifer in Bhaktapur (Source Bhaktapur Municipality, 2012)

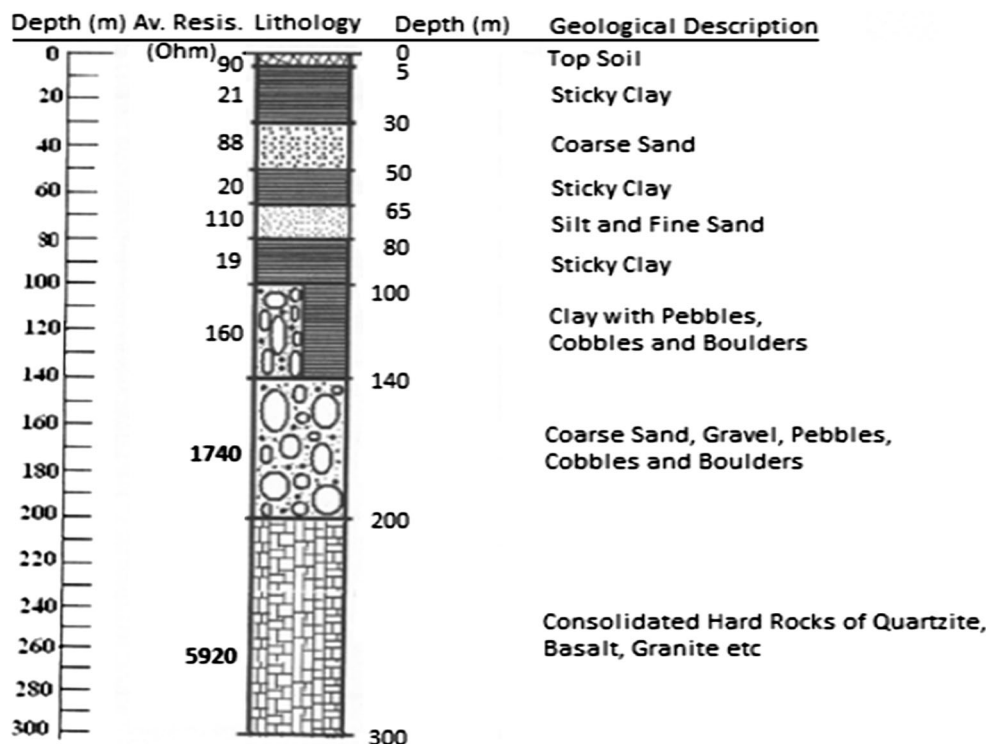
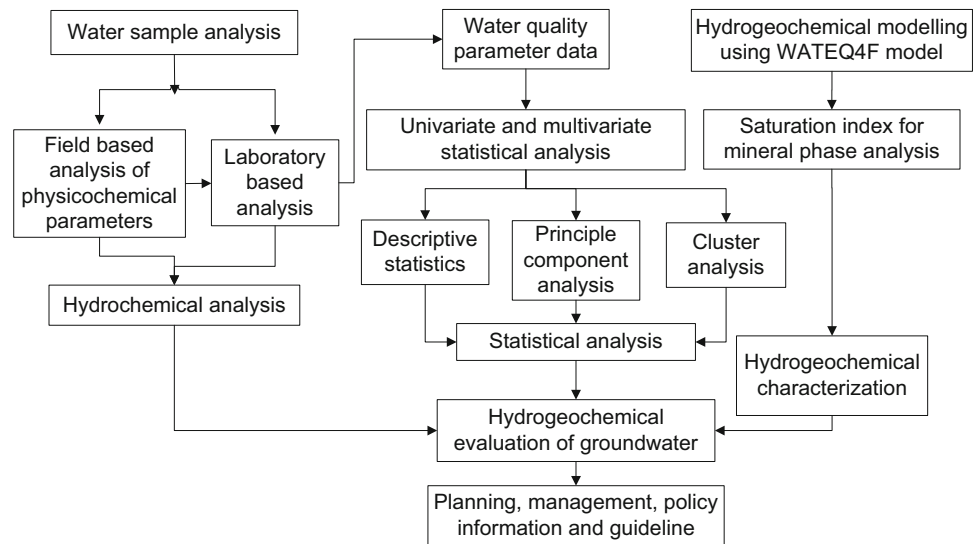


Fig. 3 Flow chart depicting the methodology applied in the study



iron (phenanthroline method), nitrate–nitrogen (Macherey–Nagel test kit method), ammoniacal-nitrogen (Macherey–Nagel test kit method), orthophosphate (ammonium molybdate method), arsenic (Quantofix arsenic test kit method) and fluoride (SPADNS method) were measured from the collected samples.

Statistical analysis

Central tendency and distribution were calculated to analyze the statistical properties of the physicochemical parameters at all the sampled observation well locations for the three seasons in the year 2007. Chemometric analysis of the groundwater dataset was performed using principal component analysis (PCA) and cluster analysis (CA) technique with the application of statistical package for social sciences (SPSS) software package (SPSS Inc., version 18). PCA was applied on experimental data after standardizing through z-scale transformation to avoid misclassification due to wide differences in data dimensionality (Simeonov et al. 2003; Singh et al. 2009). PCA provides information about the variables responsible for the spatial variation in groundwater quality (Avtar et al. 2013). The spatial distribution of variables was calculated using univariate statistical analysis. The effects of the variables and their statistical correlation at a given time were calculated by multivariate analysis, a technique for handling large and complex datasets to get better information (Singh et al. 2015). Correlation matrix was used to analyze dependency among the physicochemical parameters. CA was also applied which groups the parameters into different classes or sub-groups based on similarities within a class and dissimilarities between the classes (Johnson and Wichern 2002; Singh et al. 2009).

Hydrogeochemical analysis for mineral phases using WATEQ4F

WATEQ4F is a thermodynamic model which calculates the saturation index (SI). The saturation index of a mineral is obtained from Eq. (1) (Appelo and Postma 2005)

$$SI = \log\left(\frac{IAP}{K_t}\right), \tag{1}$$

where IAP is the ion activity product and K_t is the solubility product. When SI is below zero, the water is undersaturated with respect to the mineral in question. An SI of zero means water is in equilibrium with the mineral, whereas an SI greater than zero means a supersaturated solution with respect to the mineral in question. Saturation indices indicate whether the water is in equilibrium or not with respect to mineral in question (Chidambaram et al. 2011; Singh et al. 2012).

Results and discussion

Hydrogeochemical analysis of groundwater

The average water temperature in all the seasons was 24.5 °C. As for pH, an average value of 7.5 occurred in the water samples across three seasons. Even though no health-based guideline occurs for pH, values obtained for each of the samples falls under an optimum range of 6.5–9.5. The pH is of major importance in determining the corrosivity of water.

The study shows that 98.21 % (well water) and 8 % (stone spout water) in pre-monsoon season, 92.86 % (well water), and 44 % (stone spout) in monsoon season and 89.29 % (well water) and 8 % (stone spout) in post-

monsoon season exceeded the WHO permissible value for conductivity, i.e., 500 $\mu\text{S}/\text{cm}$. The unusual rise in conductivity measurement in water is the sign of accumulation of pollutants (Trivedy and Goel 1984). Studies of Pandey and Kazama (2011), Bajracharya (2007) and Pant (2011) also revealed higher conductivity value in the drinking water sources in Kathmandu and Lalitpur districts. The maximum conductivity value in all water sources in monsoon season may be due to dissolution of various natural salts from sewage or urban runoff.

The result showed that 10.71 % (well water) and 12 % (stone spout water) in pre-monsoon season, 100 % (well water and stone spout water) in monsoon season and 16.07 % (well water) and 28 % (stone spout water) in post-monsoon season exceeded the WHO permissible value, i.e., 5 NTU (Nephelometric Turbidity Unit). Turbidity is the result of suspended and colloidal matters such as clay, silt, finely divided organic matters and other microorganisms, and it is also known to be the aspect of optical property that causes scattering and absorption of light rather than transmission without any change in direction or flux level through the sample (APHA 1999). Higher turbidity in water is an indication that water is unfit for domestic and industrial uses (APHA 1999).

Among all the sources, in all the seasons of investigation period, the highest total alkalinity of 420 mg/L was recorded for well water in monsoon season, for stone spout in post-monsoon season whilst the lowest total alkalinity of 60 mg/L was recorded for tube well in monsoon season. HCO_3^- is the most common anion of groundwater, basically derived from soil carbon dioxide (CO_2) (Yammani et al. 2008). The presence of carbonic acid is indicated when pH is less than 4.5, bicarbonate when pH is between 4.5 and 8.2, and carbonate is present when pH is above 8.2 (Todd 2005). The pH below 8.3 in water samples could be the reason for the absence of carbonate ions. In the drinking water sources of the Bhaktapur Municipality, the total alkalinity was solely due to bicarbonate (HCO_3^-) ions. The alkalinity is used in the interpretations and control of water and wastewater processes (APHA 1985).

Water sample test showed that carbonate alkalinity was absent, so the hardness can be solely linked to the carbonate hardness. None of the samples in the three season exceeded the WHO hardness standard, i.e., of 500 mg/L. Depending upon interactions with other factors such as pH and alkalinity, hard water can cause increased soap consumption and scale deposition in the water distribution system, as well as in heated water applications where insoluble metal carbonates are formed, coating surfaces and reducing the efficiency of heat exchangers (WHO 2011a).

Chloride in the form of chloride ion (Cl^-) is the major inorganic anion present in water and wastewater. The

analytical results showed that of the samples, 1.79 % (well water) in pre-monsoon season, 12.5 % (well water) in monsoon season and 7.14 % (well water) in post-monsoon season exceeded the WHO permissible value for chloride, i.e., 250 mg/L. The main sources of chloride in drinking water are natural sources, sewage and industrial effluents, urban runoff containing de-ionizing salts and saline intrusion (Appelo et al. 1993). Sewage and urban runoff infiltrated into the groundwater may be the reason for high chloride content in these water samples. Water containing 250 mg/L of chloride ions possess detectable salty taste if the cation is sodium, whilst the typical salty taste may be absent with as much as 1000 mg/L chloride if cations like calcium and magnesium are present. This may harm metallic pipes and structures as well as growing plants (WHO 2004).

Among all the sources in all the seasons of investigation period, the highest iron content was recorded for stone spout water in post-monsoon season. 73.21 % of well water and 56 % of stone spout in pre-monsoon season; 66.07 % of well water and 64 % of stone spout in monsoon season; 94.64 % of well water and 72 % of stone spout in post-monsoon season exceeded the WHO permissible value for iron content in drinking water of 0.3 mg/L. Taste is not usually noticeable at iron concentrations below 0.3 mg/L, although turbidity and color may develop in piped systems at levels above 0.05–0.1 mg/L (WHO 2003). The ground water under anaerobic condition may contain iron (II) without discoloration or turbidity in the water when pumped directly from a well, while turbidity and color can be developed in piped systems at iron levels above 0.05–0.1 mg/L. Above 0.3 mg/L, there may be staining of laundry and plumbing. It is advisable as safe for drinking water containing 1–3 mg/L iron. It is considered as a nuisance even though it has got little concern for health problem (APHA 1985).

Nitrate concentration was below the detection limit for some samples of tube well. The highest concentration of 40 mg/L occurred for few samples of well water in post-monsoon season. None of the samples in all three season exceeded the WHO standard for nitrate content in drinking water, i.e., 50 mg/L. Nitrate in groundwater may result from point sources such as sewage disposal systems and livestock facilities, non-point sources such as fertilized agricultural lands, parks or naturally occurring sources of nitrogen. Higher nitrate content in drinking water is associated with the epidemiological evidence for methemoglobinemia in infants, which results from short-term exposure and is protective for bottle-fed infants and, consequently, other population groups the outcome of which is complicated by the presence of microbial contamination or other gastrointestinal infections (WHO 2011b).

Water samples from 7.14 % of well, 25 % of tube well and 8 % of stone spout in pre-monsoon season; from 3.57 % of well and 4 % of stone spout in monsoon season and from 5.36 % of well water in post-monsoon season exceeded the WHO permissible value for ammonia content which is 1.5 mg/L for drinking use. Presence of ammonia in water is also an indication of organic pollution of recent origin. Higher ammonia concentration is related to toxicity which increases with pH because at higher pH, most of the ammonia remains in gaseous form and vice versa (Trivedi and Goel 1986). Ammonia has a toxic effect on healthy humans only if the intake becomes higher than the capacity to detoxify (Nelson and Cox 2008).

Among all the sources in all the seasons of investigation period, highest phosphate concentration of 3.62 mg/L was recorded for stone spout in pre-monsoon season. Water supplies may contain phosphates derived from natural contact with minerals or through pollution or application of fertilizers, sewage and industrial wastes. Groundwater are, therefore, likely to have higher phosphate concentration (DeZuan 1997).

Arsenic content of water in the study area ranged from 0 to 0.01 mg/L with a mean value of 0.07 mg/L. None of the samples in all three season exceeded the WHO standard for arsenic content in drinking water, i.e., 0.01 mg/L. In water, arsenic is found in the form of arsenite (+3), arsenate (+5) and organic arsenicals. Toxicity of arsenic depends upon its specific chemical form (Katsoyiannis and Zouboulis 2002). Arsenic in drinking water is highly undesirable because of its toxicity. There is the need to explore additional arsenic mitigation options that can ensure access to safe drinking water in a sustainable way (Neupane et al. 2014).

Except well water in pre-monsoon season, all sources contained fluoride within the WHO standard value for drinking. 25 % of the samples (well water) in pre-monsoon season exceeded the WHO permissible value for fluoride content in drinking water, i.e., 1.5 mg/L. Among all the sources of water in all the seasons of investigation period, the highest fluoride content was 1.89 mg/L recorded for well water in pre-monsoon season. The well water with high-fluoride concentrations is usually associated with a NaHCO_3 type groundwater (Brunt et al. 2004). Consequence of high-fluoride levels in water results in disfigurement of teeth and stiffening of the bone joints, particularly that of spinal cord (Saxena 2013).

In the developing countries, the dynamics of urbanization and population growth are exerting high pressure on the quality of drinking water resources (Islam et al. 2014; Thakur et al. 2013). Surface and groundwater pollution are mainly due to sewage, domestic wastes, industrial effluents and agricultural runoff containing toxic chemical substances (Diwakar and Thakur 2012).

Statistical analysis

Descriptive and multivariate statistics were applied for the classification, modeling and interpretation of large dataset. An overall descriptive statistics of the physicochemical properties is shown in Table 1.

The descriptive statistics of the mean of 255 samples showed that mean of pH is 7.548 ± 0.021 . The conductivity of the groundwater fails to meet the WHO standard while lies within the Nepal standards with the mean of $632.694 \pm 26.337 \mu\text{S}/\text{cm}$. Turbidity of the groundwater was also above the WHO as well as the Nepal Standards with mean of $13.767 \pm 0.661 \text{ NTU}$. As for anions, Cl^- , NO_3^- , F^- and PO_4^{2-} , the content values were 141.765 ± 8.340 , 9.667 ± 0.753 , 0.469 ± 0.034 and $1.030 \pm 0.048 \text{ mg/L}$, respectively. Heavy metal contents of iron fail to meet the WHO and the Nepal water standards with the mean contents of $0.760 \pm 0.062 \text{ mg/L}$. Total alkalinity of the water had value of $273.686 \pm 5.515 \text{ mg/L}$. Total hardness of the groundwater was $212.047 \pm 7.792 \text{ mg/L}$ while the ammonia content was $0.549 \pm 0.067 \text{ mg/L}$. The measures of skewness and kurtosis give ideas on the nature of distribution of data. The negative values of skewness for pH, conductivity, chloride, alkalinity, total hardness and arsenic represents that they are skewed left, meaning that more of lower range value from the mean value is dominant in the given dataset for that variable than that for the higher range values. Similarly, the positive skewness for variables like turbidity, iron, phosphate, nitrate, ammonia and fluoride represent skewness towards right. Kurtosis provides the estimates for the shape of the given distribution in comparison to the normal distribution. High values for iron, total alkalinity and ammonia means more of the variance is the result of infrequent extreme deviations, as opposed to frequent modestly sized deviations.

Correlation matrix

The correlation matrix in Table 2 shows significant value (non-diagonal) in the threshold $\alpha = 0.05$ for a total of $n = 255$ individuals. The relationship is highly significant ($r > 0.8$, $n = 255$) for free CO_2 with Cl^- and arsenic. Salinity is mainly controlled by EC and arsenic, fluoride, Cl^- , showing a significant relationship ($r > 0.7$). Non-carbonate hardness was seen to be the major contributor to the TH of groundwater since a significant relationship ($r > 0.7$) was obtained between TH and Cl^- . Arsenic was seen to contribute significantly to turbidity ($r > 0.7$). No such significant correlation was observed with respect to contribution via any of the ions to turbidity.

Table 1 Descriptive statistics of the physicochemical properties of the samples in the study area (mean of three seasons)

	Range	Minimum	Maximum	Mean		SD	Variance	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	SE	Statistic	Statistic	Statistic	SD	Statistic	SE
pH	0.967	6.867	7.833	7.548	0.021	0.196	0.038	-1.121	0.261	1.654	0.517
Conductivity	964.000	129.000	1093.000	632.694	26.337	242.811	58957.252	-0.329	0.261	-1.010	0.517
Turbidity	31.067	2.000	33.067	13.768	0.662	6.101	37.223	0.711	0.261	0.432	0.517
Chloride	277.027	14.200	291.227	141.765	8.340	76.890	5912.005	-0.428	0.261	-1.274	0.517
Total alkalinity	280.000	83.333	363.333	273.686	5.515	50.845	2585.191	-1.686	0.261	4.680	0.517
Total hardness	306.667	71.333	378.000	212.047	7.792	71.842	5161.278	-0.234	0.261	-0.868	0.517
Iron	3.567	0.000	3.567	0.760	0.062	0.570	0.325	2.257	0.261	7.237	0.517
Phosphate	1.833	0.180	2.013	1.030	0.048	0.447	0.199	0.093	0.261	-0.814	0.517
Nitrate	35.000	0.000	35.000	9.667	0.753	6.943	48.200	1.263	0.261	1.840	0.517
Ammonia	3.000	0.000	3.000	0.549	0.067	0.614	0.377	1.771	0.261	3.475	0.517
Arsenic	0.010	0.000	0.010	0.007	0.000	0.005	0.000	-0.920	0.261	-1.182	0.517
Fluoride	1.023	0.037	1.060	0.469	0.034	0.316	0.100	0.320	0.261	-1.408	0.517
Valid N (listwise)											

Principal component analysis

PCA is applicable to the multivariate analysis of ground-water (Shrestha and Kazama 2007). Principal component (PC) was extracted from the 255 water samples of the Bhaktapur Municipality and PCA was performed for the original variables. The first three principal components were picked up, with the cumulative contribution rate up to 62.2 %, i.e., the three PCs already contained 62.22 % information of 14 original variables. The component matrix involving component 1 and 2 is shown in the Table 3.

Component matrix shows correlation between variables and the extracted components. One parameter and the corresponding principal component will have more significant correlation if the absolute value of load factor is near to 1. It presents positive correlation when the coefficient is positive and negative correlation if the coefficient is negative. From the Table 3, it is seen that component 1 has positive load factors on the variables Cl⁻, EC, arsenic, TH, F⁻, PO₄²⁻, NO₃⁻, NH₃, pH, TA and iron while negative factor loading on the variables as temperature, turbidity which indicate that PC1 is the inclusive measurement for the salinization of ground-water. High positive load factor on Cl⁻ might be due to the leaching of domestic and organic wastes. Similarly, high positive factor load of trace metals indicate leaching from the soil and industrial waste sites, organic and anthropogenic pollution. Similarly, PC2 has larger positive load factor on the variables of turbidity, pH and TA, indicating that it is the inclusive measurement of alkalization of the groundwater.

Similarly, the component plot (Fig. 4) represents the same information in the rotated space. Most of the variable lie on the upper right quadrant, signifying that they are positively co-related with both the components (1 and 2), the degree of co-relation being the function of distance from the centreline. On the other hand, point location on the extreme right for fluoride, phosphate, Cl⁻, conductivity, TH and arsenic represents that component 1 has higher positive factor loadings on such variables. Similarly, with intermediate loadings are variables like pH, Total alkalinity, NO₃⁻ and NH₃ for the component 1. Temperature is seen to correlate negatively with both the principle components. Component 2 has significant negative loadings for variables like NO₃⁻, arsenic and NH₃ and significant positive loadings on variables as turbidity, pH and total alkalinity.

Communalities matrix (Table 4) displays high extraction communalities for all variables except temperature, Fe⁺², NO₃⁻ and NH₃, indicating that extracted components represents the variables well. Extraction communalities are estimates of the variance in each variable accounted for by the factors (or components) in the factor solution. We can interpret that for most of the variables including pH, conductivity, turbidity, free CO₂, chloride, alkalinity, hardness, phosphate, arsenic and fluoride, the variance is well explained by the principle components. High extraction values for these variables represent high part of their variance is shared with other variables, and not due to measurement error. Initial communalities, which are the estimates of the variance in each variable, accounted for by all components is 1 in principal components analysis.

Table 2 Correlation between the mean values of various components of groundwater for three seasons in the study area

	Temperature	pH	Conductivity	Turbidity	Free CO ₂	Chloride	Total alkalinity	Total hardness	Iron	Phosphate	Nitrate	Ammonia	Arsenic	Fluoride
<i>Correlation</i>														
Temperature	1.000	-0.112	-0.352	-0.095	-0.226	-0.253	-0.018	-0.239	-0.087	-0.164	-0.139	-0.247	-0.276	-0.220
pH	-0.112	1.000	0.411	0.346	0.260	0.468	0.460	0.591	0.109	0.304	0.008	0.000	0.239	0.298
Conductivity	-0.352	0.411	1.000	-0.114	0.739	0.791	0.302	0.763	0.063	0.538	0.280	0.190	0.768	0.682
Turbidity	-0.095	0.346	-0.114	1.000	-0.282	-0.174	0.266	0.032	0.188	-0.089	-0.215	-0.086	-0.319	-0.123
Free CO ₂	-0.226	0.260	0.739	-0.282	1.000	0.847	0.056	0.641	0.040	0.476	0.248	0.204	0.906	0.619
Chloride	-0.253	0.468	0.791	-0.174	0.847	1.000	0.175	0.799	0.100	0.576	0.330	0.244	0.881	0.562
Total alkalinity	-0.018	0.460	0.302	0.266	0.056	0.175	1.000	0.386	0.079	0.213	0.102	0.079	-0.019	0.293
Total hardness	-0.239	0.591	0.763	0.032	0.641	0.799	0.386	1.000	0.134	0.537	0.337	0.123	0.690	0.547
Iron	-0.087	0.109	0.063	0.188	0.040	0.100	0.079	0.134	1.000	-0.036	0.026	0.015	-0.013	0.021
Phosphate	-0.164	0.304	0.538	-0.089	0.476	0.576	0.213	0.537	-0.36	1.000	0.264	0.91	0.521	0.414
Nitrate	-0.139	0.008	0.280	-0.215	0.248	0.330	0.102	0.337	0.026	0.264	1.000	0.110	0.314	0.188
Ammonia	-0.247	0.000	0.190	-0.86	0.204	0.244	0.079	0.123	0.015	0.091	0.110	1.000	0.204	0.136
Arsenic	-0.276	0.239	0.768	-0.319	0.906	0.881	-0.019	0.690	-0.013	0.521	0.314	0.204	1.000	0.634
Fluoride	-0.220	0.298	0.682	-0.123	0.619	0.562	0.293	0.547	0.021	0.414	0.188	0.136	0.634	1.000

Cluster analysis

CA was applied to the data sets to find the existing similarity groups between the sampling stations (0–25 scale). A dendrogram was produced (Figs. 5, 6) through hierarchical agglomerative algorithms using squared Euclidean distance which allows the backward or forward tracing to any

Table 3 Principal component loadings

	Component	
	1	2
<i>Component matrix</i>		
Chloride (Cl ⁻)	0.929	-0.064
Conductivity (EC)	0.899	0.030
Arsenic (As)	0.889	-0.324
Total hardness (TH)	0.865	0.243
Fluoride (F ⁻)	0.737	0.002
Phosphate (PO ₄ ²⁻)	0.662	0.013
Nitrate (NO ₃ ⁻)	0.388	-0.214
Temperature	-0.353	-0.035
Ammonia (NH ₃)	0.256	-0.138
Turbidity	-0.154	0.792
pH	0.498	0.661
Total alkalinity (TA)	0.305	0.658
Iron (Fe)	0.081	0.321

individual case or clustering at any level. CA helps in grouping all sampling stations into statistically meaningful subsets. The results showed that the CA technique showed its usefulness in the classification of water samples, hence the number of sampling sites and respective cost could be diminished in future monitoring plans. The following sites formed cluster for well water samples (Fig. 5) on the basis of similarity in pollution. Sites 2, 18, 16, 40, 12, 36, 30, 42, 32, 53, 31, 45, 23, 35, 37 and 26 formed cluster 1. Sites 7, 56, 55, 34, 21, 48, 49, 44, 43, 25, 33 and 24 formed cluster 2. Sites 5, 51, 47, 39, 54, 46, 1, 27, 29, 28, 50, 9, 22, 15, 38, 52 and 41 formed cluster 3. Sites 3, 17, 6, 14, 20, 8, 19, 11, 13, 10 and 4 formed cluster number 4. Similarly, in the case of stone spout sampling sites (Fig. 6), two distinct clusters could be observed in the dendrogram. The sampling sites 11, 20, 5, 8, 10, 14, 4, 21, 2, 23, 1, 13, 17, 15, 25 and 19 formed cluster number 1 whereas the remaining sites 6, 22, 16, 9, 12, 24, 3, 8 and 7 formed the cluster number 2. This is to say that four different subsets or close groups can be accounted for in the study area in terms of their similarities for well water and in case of stone spout water, two such distinct subsets could be delineated. For well water, the sub-group represented by first cluster as described above and represented in Fig. 5 has closer resemblance with the with the sub-group described by second cluster and less resemblances with those by third and fourth clusters. Thus, the dendrogram provides representative picture of the nature of the sample sites so that future water

Fig. 4 Component plot of the mean of three seasons

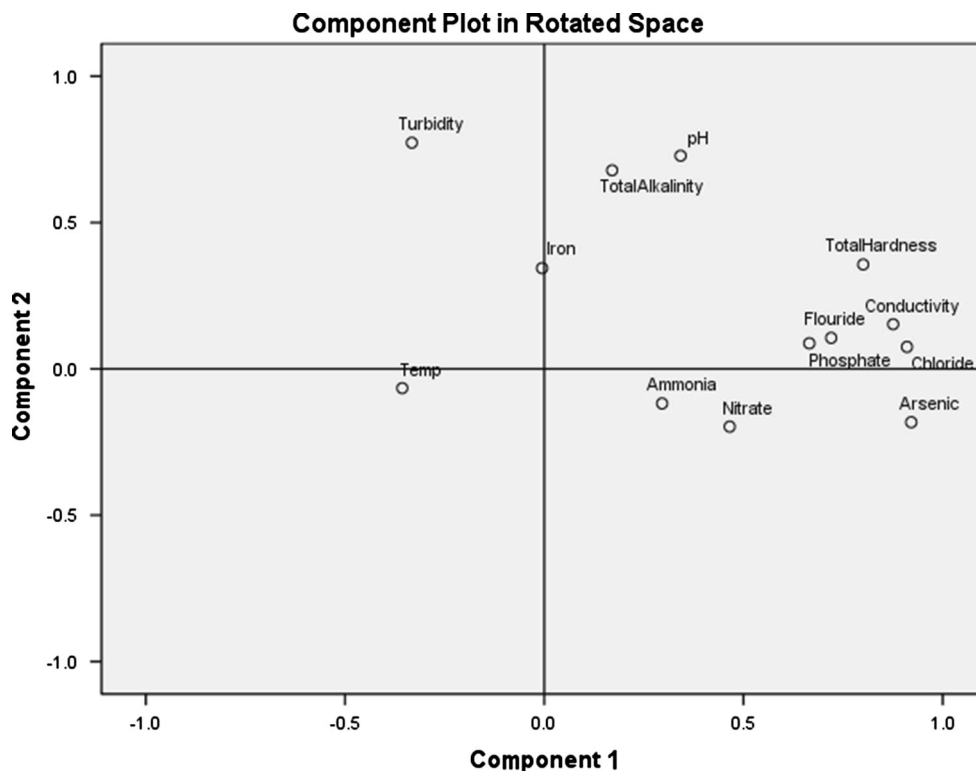


Table 4 Communalities matrix for various variables

	Initial	Extraction
Temperature	1.000	0.126
pH	1.000	0.685
Conductivity	1.000	0.809
Turbidity	1.000	0.652
Free CO ₂	1.000	0.812
Chloride	1.000	0.866
Total alkalinity	1.000	0.525
Total hardness	1.000	0.807
Iron	1.000	0.109
Phosphate	1.000	0.438
Nitrate	1.000	0.196
Ammonia	1.000	0.085
Arsenic	1.000	0.896
Fluoride	1.000	0.543

resources analysis could be eased and sampling locations could be substantially optimized in regards to the similarities and/or differences among the sampling locations.

WATEQ4F estimations for mineral phases

Change in the saturation index helps to distinguish between various stages of hydrogeochemical evolution (Chidamabaram et al. 2008). In addition, it helps to determine which geochemical process is important in controlling water chemistry of that particular area (Aghazadeh and Asghari 2010). This information is vital to protecting and remediating the water bearing system. Generally, as groundwater moves through an aquifer, it initially dissolves the rocks and releases minerals at varying rate due to rock–water interaction in the water systems (Singh et al. 2013b). The Saturation Index (SI) values were computed for the water samples which showed that, in general, all the samples were under-saturated with respect to ferrihydrite, siderite, strengite and vivianite minerals in both pre-monsoon and post-monsoon seasons. In contrast, water samples were super saturated with respect to goethite mineral in both the seasons and hence, the water did not have potential to dissolve more iron, but if further iron will come to the water system, then it will precipitate. However, high degree of super saturation showed that the goethite mineral had responses to temperature gradient of the reactions. Generally, the minerals like ferrihydrite, siderite, strengite and vivianite solutions showed very high degree of under-saturation in all seasons which indicates that they are affected largely by the dilution. The collected samples from stone spout showed that most water samples were

under-saturated with respect to a particular mineral. Goethite mineral was saturated with respect to water during both pre-monsoon and post-monsoon periods (Figs. 7, 8). For well water, goethite mineral was highly saturated during both pre-monsoon and post-monsoon seasons. Also, the mineral vivianite shows saturation, though not highly, in most of the sampling locations (Fig. 8).

The paper outlines the inherent hydrochemical characteristics of groundwater in the research area with estimates of potability of such source with respect to values of groundwater quality parameters. Such an evaluation will provide the necessary guidance for water quality management policy initiative. The univariate and multivariate statistical tools provide necessary grounds for reduction and subsequent evaluation of large dataset to produce concrete results which high implementation value. The cluster analysis also helps optimize the monitoring strategy both spatially and temporally. Evaluation of groundwater hydrogeochemistry acts as a tool to sustainable groundwater management. The saturation indices for various minerals help to identify the impacts from further mineral intrusion into the aquifer. Water resources development and management should explicitly consider all these facets.

Conclusion and recommendation

The study combined field and laboratory-based physico-chemical analysis, statistical analysis and hydrogeological modeling (WATEQ4F model) for the computation of SI.

From the hydrochemical analysis, it was found that most or all of the samples exceeded WHO GLV for conductivity, turbidity and iron while none of the samples exceeded the range for arsenic and hardness. Three principle components could be characterized in the study area with cumulative contribution rate up to 62.2 %. The hierarchical cluster analysis grouped different sampling sites into four clusters for well water and two clusters for stone spout water. Based on the obtained information, it is possible to design optimal sampling strategy which could reduce the number of sampling stations and the cost of sampling in the future. Hydrochemical evaluation of the groundwater was aided by depicting intricate relationship, i.e., co-relation between/among the parameters and cluster analysis of sampling sites according to the parameter values. Generally, in a complex groundwater system, one variable produces certain degree of effect on the other variable which necessitates the evaluation of statistical co-relation among them. In the water quality assessment, multivariate analysis aids in the identification of pollution source/factors and understanding spatial/temporal variations in groundwater

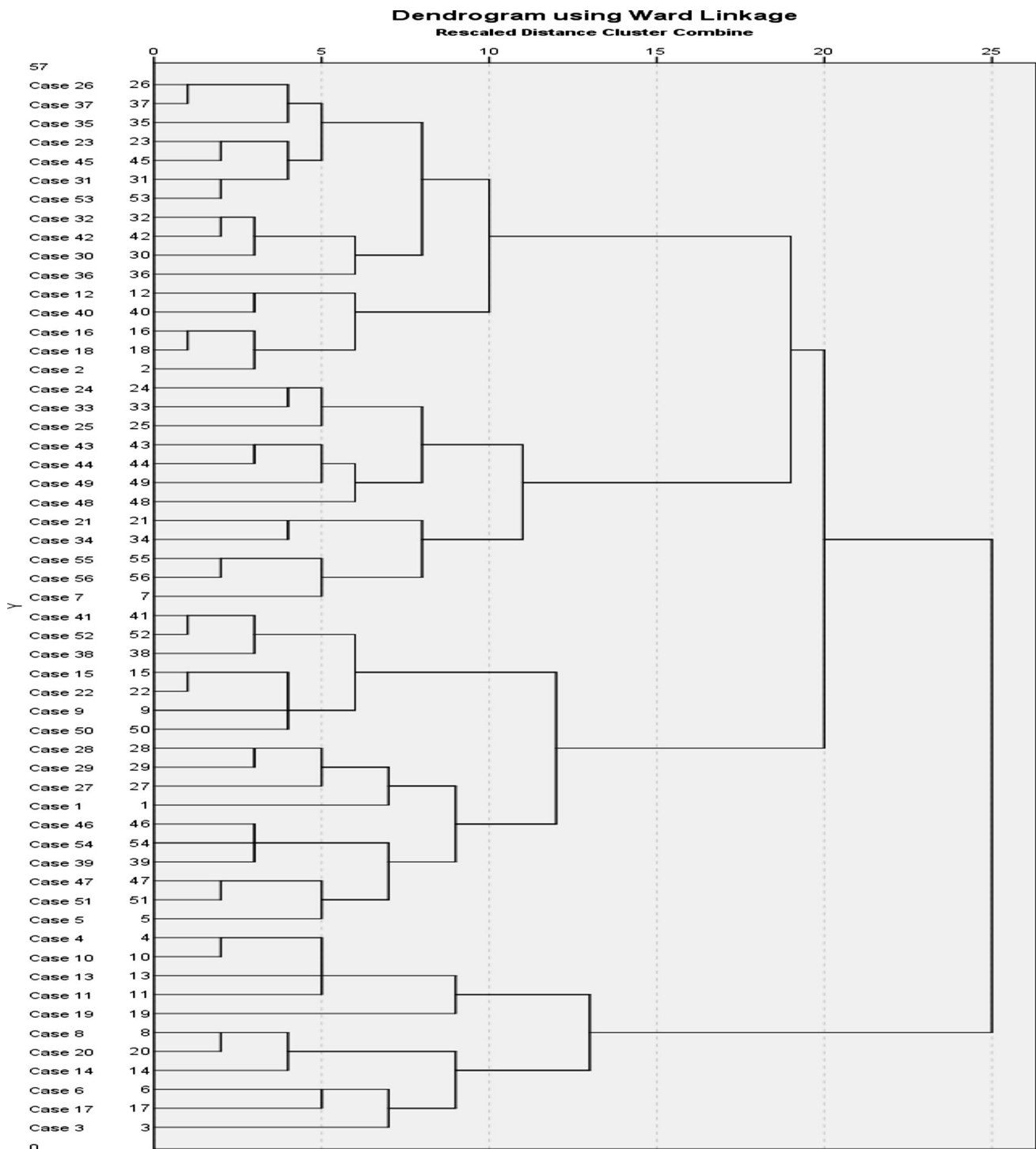


Fig. 5 Dendrogram from hierarchical agglomerative analysis of three seasons showing sampling site clusters for well in the study region, the Bhaktapur Municipality, Nepal

quality for effective groundwater quality management. Future research work needs to focus on the predictive modeling of SI and X-ray diffraction. The presence of high degree of supersaturation in goethite mineral indicates its response to temperature gradient of the reactions whereas

the high degree of under-saturation in other minerals can be attributed to the effects of dilution.

The outcomes of this research provide an insight to the current situation of groundwater system in terms of its physicochemical properties. An estimation of mineral

Fig. 6 Dendrogram from hierarchical agglomerative analysis of three seasons showing sampling site clusters for stone spout in the study region, the Bhaktapur Municipality, Nepal

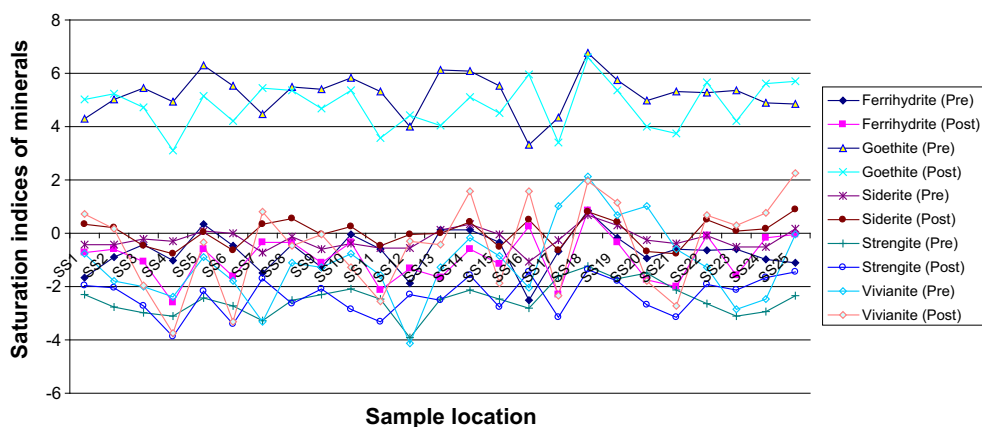
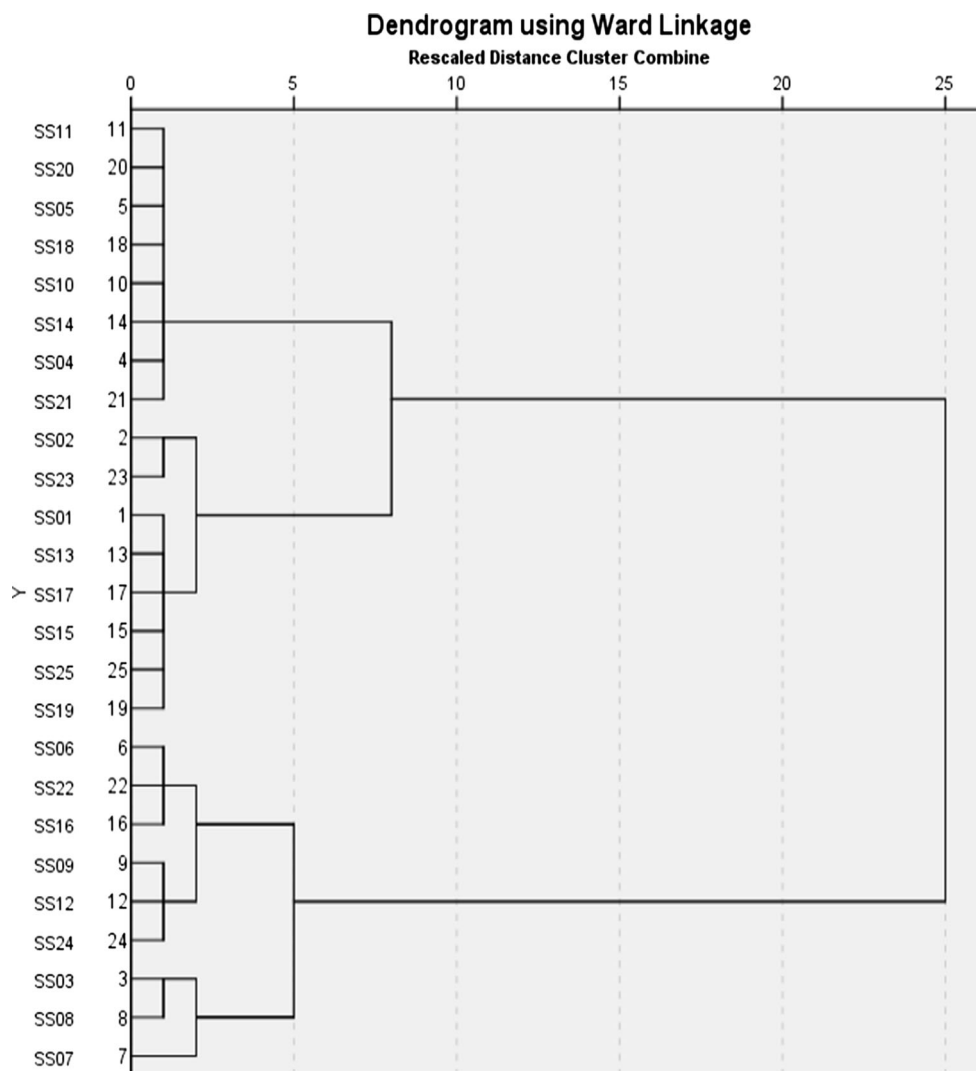


Fig. 7 Saturation indices of minerals for samples from stone spout in pre-monsoon and post-monsoon seasons

saturation state in the system as determined by weathering from natural sources and consequent impact of anthropogenic enrichment of the minerals is also provided. Thus,

the outcomes of this research guide in the formulation of plans and policies that aid in sustainable groundwater resource management. The overall assessment of the

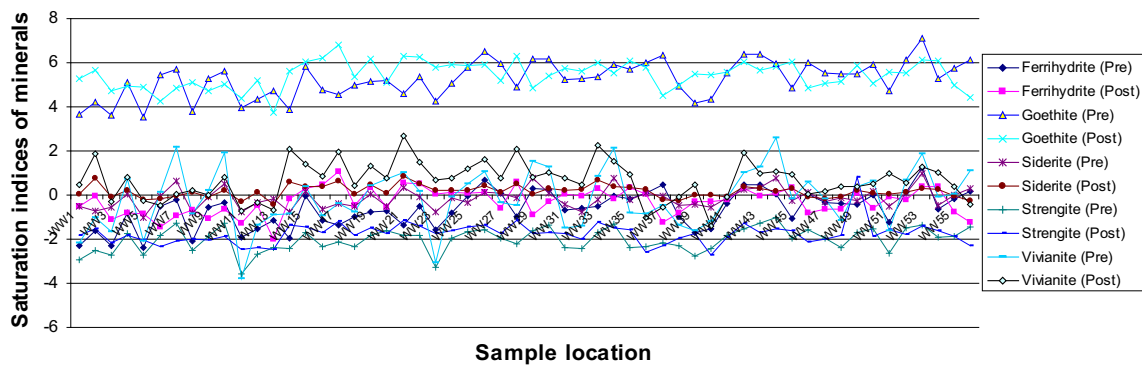


Fig. 8 Saturation indices of minerals for samples from well in pre-monsoon and post-monsoon seasons

groundwater scenario is vital to opting for suitable management intervention.

Acknowledgments The authors would like to thank Chetaki Rajya Laxmi Devi Memorial Science and Technology Foundation for partial funding assistance. We are grateful to NAST for providing laboratory facilities. We thank the Bhakatapur Municipality for providing borehole log data. We highly appreciate kind assistance from Mr. Mahesh Neupane, Department of Water Supply and Sewerage (DWSS), Government of Nepal. We are also thankful to Health and Environmental Management Society (HEMS), Kathmandu, Nepal for the valuable support.

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